Environmental Factors Behind The Scattered Wind and Hail Event on May 21, 2022

Overview:

Mid to late afternoon on Saturday, May 21st, scattered showers and thunderstorms developed across parts of northern New York and northern Vermont, while areas south remained largely dry. An anomalously warm air mass had lifted into the North Country on Saturday, with high temperatures 15 to 20 degrees above normal, reaching into the mid to upper 80s. Atmospheric conditions were initially unfavorable for thunderstorm development due to a capping inversion layer, observed at the climatological peak over the region. However, there were indications that strong surface heating and gradual erosion of the cap could allow the development of convection, despite rising heights across the region or lack of any forcing mechanism. An elevated mixed layer and the development of convective available potential energy (CAPE) exceeding 3000 J/kg, which is uncommon in this region, indicated that despite the limiting factors for convective initiation, any thunderstorm that did develop could quickly become severe. A mesoscale convective vortex that caused extensive damage in Ontario Province provided the tipping point with an outflow boundary that interacted with a lake breeze along Lake Ontario. Large hail and a number of damaging downburst wind events occurred before thunderstorms progressed east of Vermont. This review of events will assess the synoptic and mesoscale features that contributed to severe thunderstorms and the two most significant thunderstorms that impacted Williston and Highgate Springs in Vermont.

Pre-Storm Environment:

The synoptic pattern on Saturday morning featured an anomalous, deep-layer ridge centered off the US East Coast. The jet stream at 300hPa was positioned well to our north and west, with only a low amplitude upper trough positioned over New England (Figure 1). Thus, the jet stream would contribute very little to any weather activity. Even without upper divergence from a strong upper jet, the positioning of the subtle shortwave trough against the cresting upper high resulted in some upper-level diffluence across Vermont and northern New York. A cold frontal boundary at 925hPa was positioned parallel to the jet stream (Not Shown), which indicated that the cold front would only make slow progress southwards, and would not reach northern New York until the following day. There was also a shortwave trough over the region in the morning, and by the afternoon, this feature was expected to shift eastwards, which would contribute to height rises.

What raised serious questions about whether or not thunderstorms would develop was a record-breaking inversion layer. Even if daytime heating and low-level moisture are sufficient for developing thunderstorms, if a stable layer aloft prevents updrafts from getting any higher, then no storms will develop. This scenario is often called “wasted CAPE" to describe the inability for convection to develop beyond a stable inversion layer. The observed sounding in Albany, NY recorded a 700 hPa temperature of 11 °C, which set a record for the month of May, and the depth of the warm, stable layer extended several kilometers (Figure 2 and 3). Model analyzed convective inhibition was present over Vermont and northern New York as well. While forecast soundings indicated mid-level cooling would erode the cap over time, we were prepared for the possibility the record-breaking record-breaking 700 hPa temperatures would remain in place and prevent thunderstorms from taking place. However, forecast soundings leading up to the event also bore resemblance to what the meteorological community defines as a “loaded gun” sounding with an inverted V with boundary layer temperatures and dewpoints, along with steep lapse rates aloft and very dry air. In these situations, convection that manages to develop beyond the cap finds an environment favorable for vigorous updrafts that produce large hail, and the access to dry air in the mid-levels increases the potential for damaging downburst winds (Figure 4). While we saw the potential little activity would occur, we also were prepared for the possibility of rapidly developing severe thunderstorms.

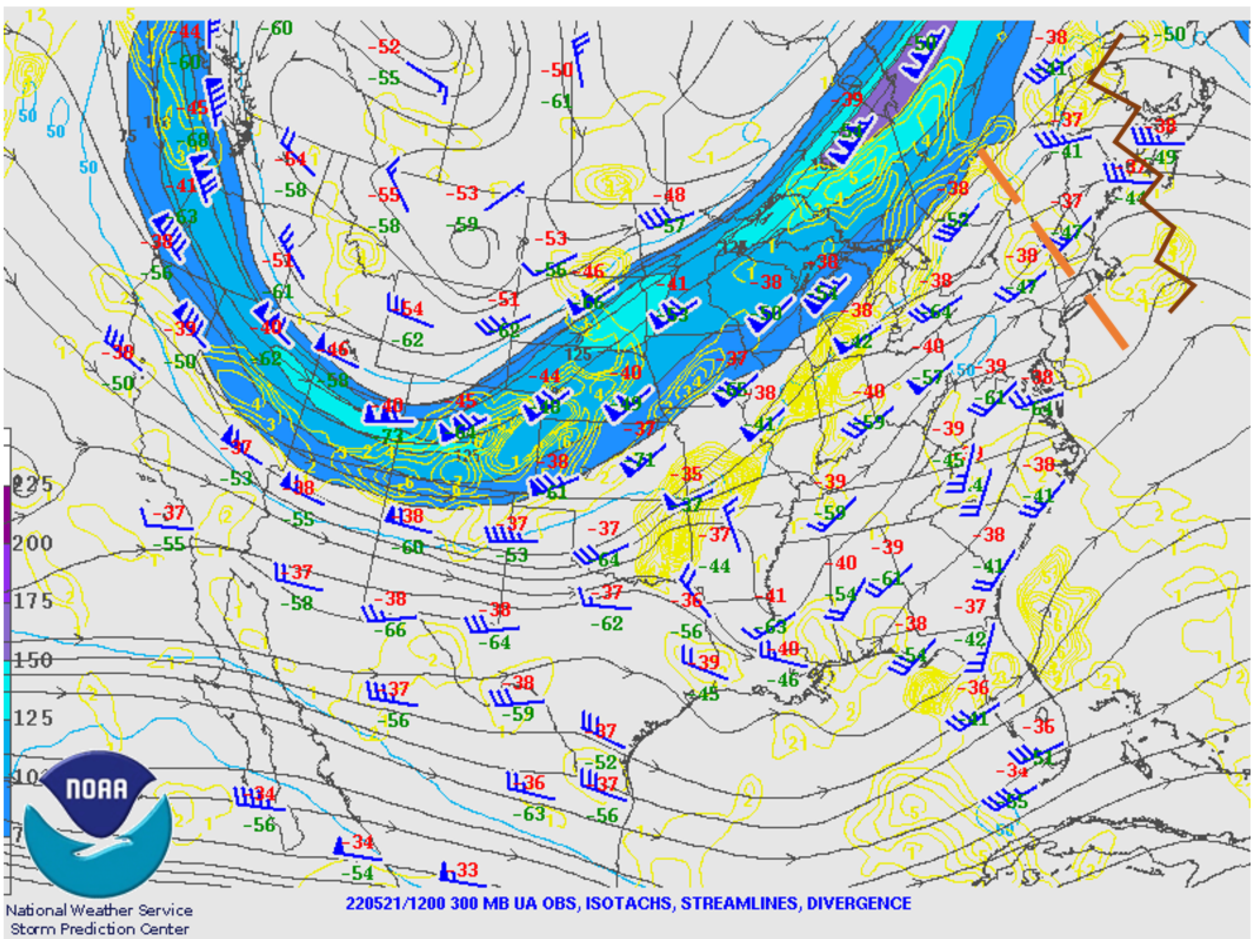

Figure 1: Storm Prediction Center upper air map at 300mb at 12Z on 21 May 2022 with plotted RAOB, isotachs shaded beginning at wind speeds in excess of 75 mph, streamlines indicating upper flow, and divergence plotted in yellow. The estimated location of the upper ridge axis in the Gulf of Maine and Nova Scotia is annotated with the brown zigzag, along with a subtle shortwave trough over New England in the dashed orange line.

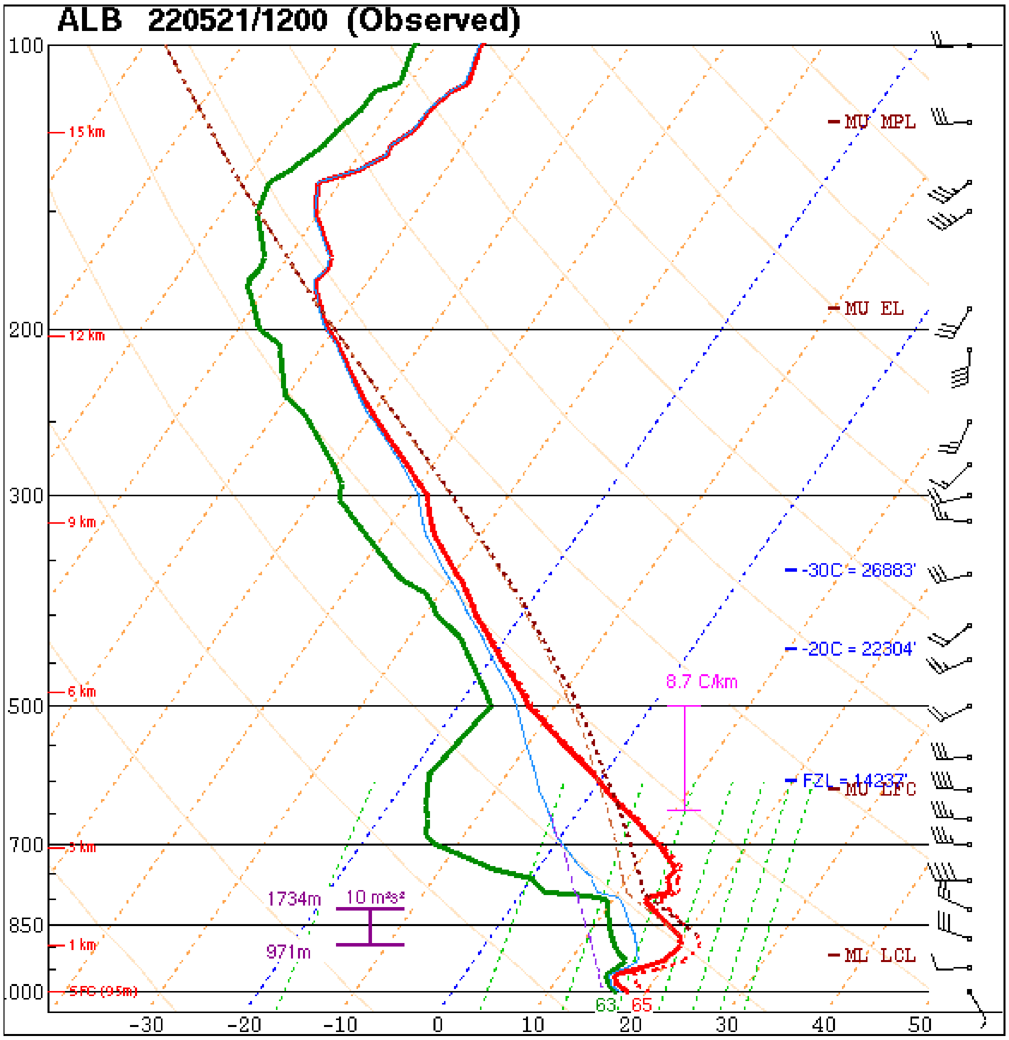

Figure 2: Storm Prediction Center plot of the 12Z ALB sounding on 21 May 22. The red line indicates temperature, the green line indicates dewpoints. The observed winds are plotted on the far right along with other meteorological parameters. The important feature is the red line indicating temperature and how it shifts to the right from the bottom of the chart before sloping to the left above the 700 line. This indicates warmer conditions higher in the atmosphere, and is the inversion layer that initially suppressed convection.

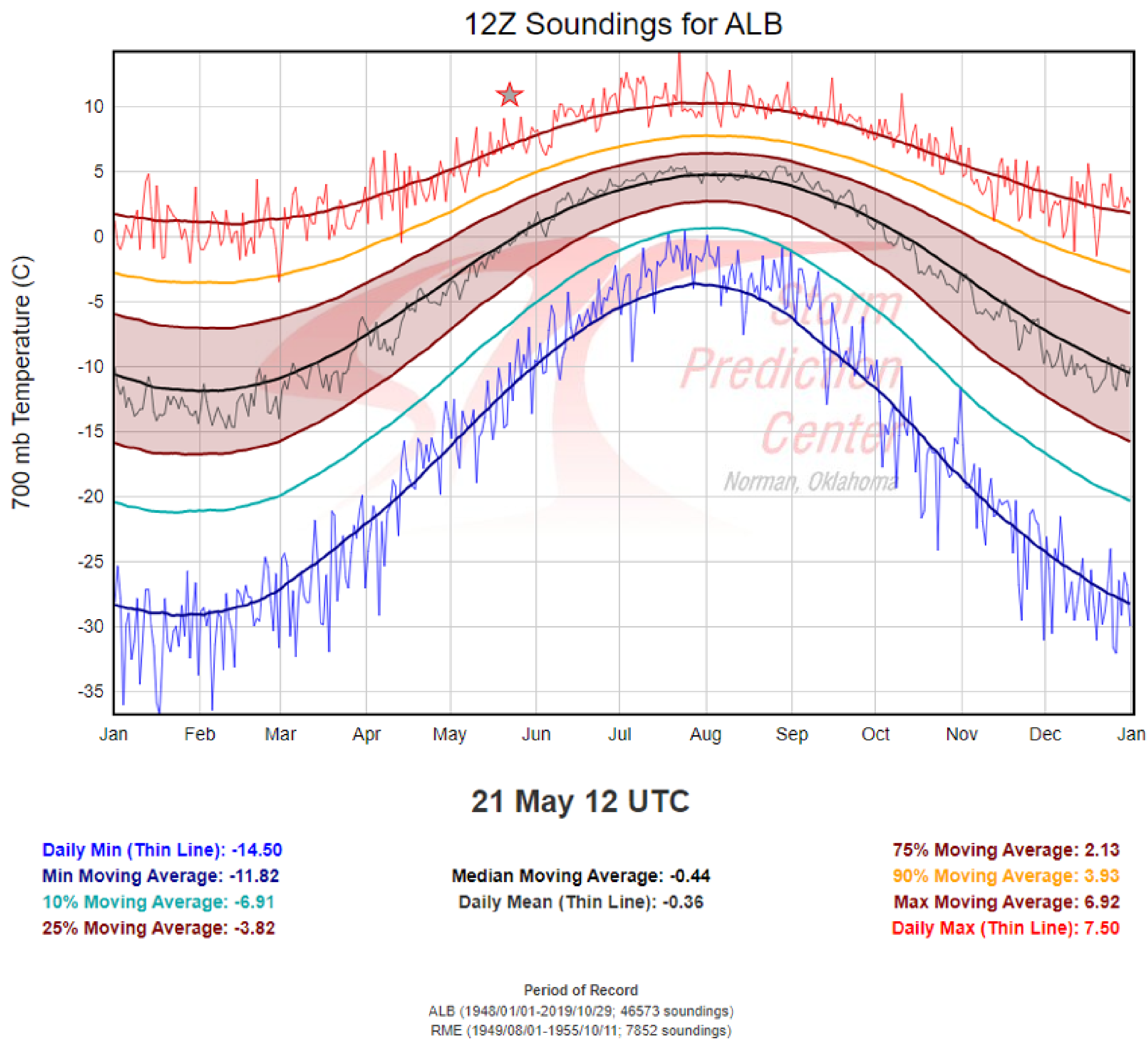

Figure 3: A graph showing the average 700mb temperature in Celsius throughout the year. The 700mb readout of 11 °C, plotted with a gray star in the approximate location of where May 21st is on the graph, breaks the previous record of 7.5 °C, shown in the thin, red line indicating the daily max. The normal value is the black line.

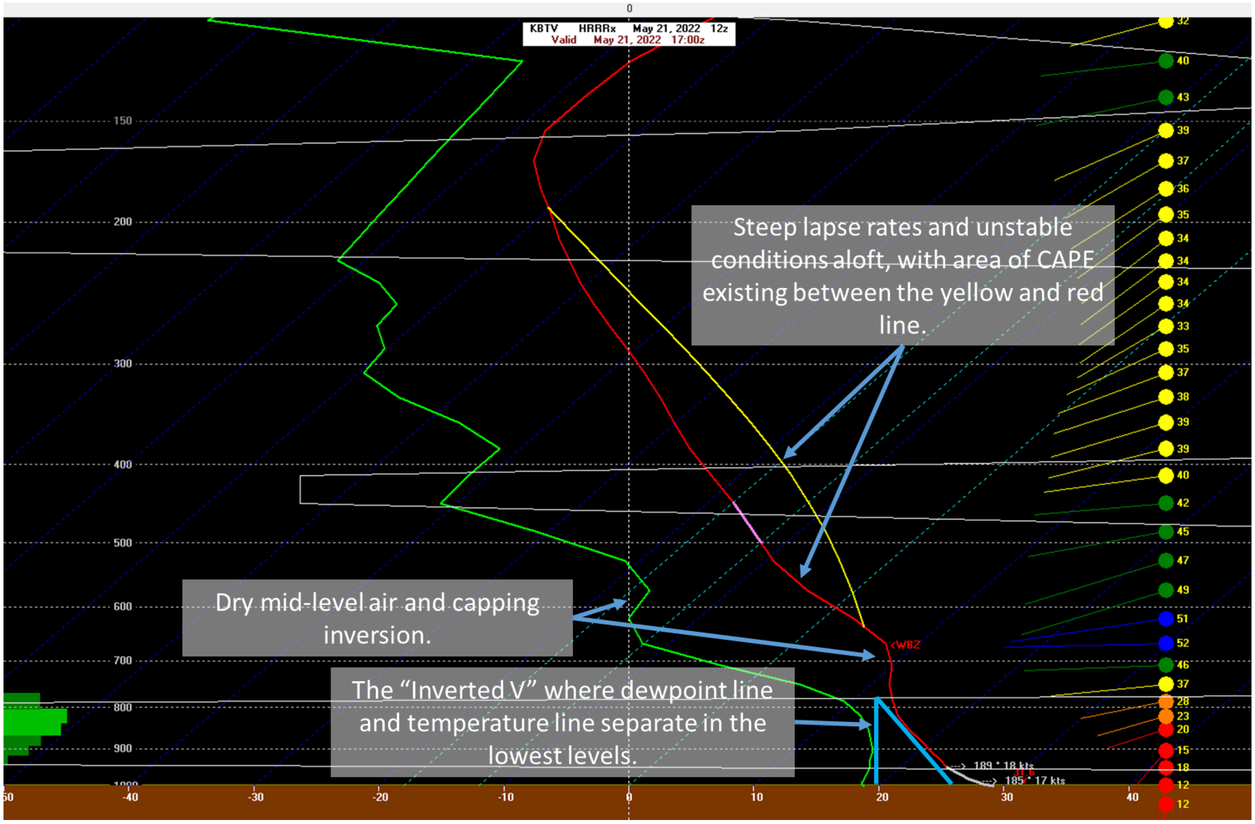

Figure 4: The "Loaded Gun" sounding forecast from the 12Z HRRR for BTV at 17Z plotted using BUFKIT. These types of soundings feature unstable conditions aloft, the presence of a warm layer, and the inverted V in the lowest levels.

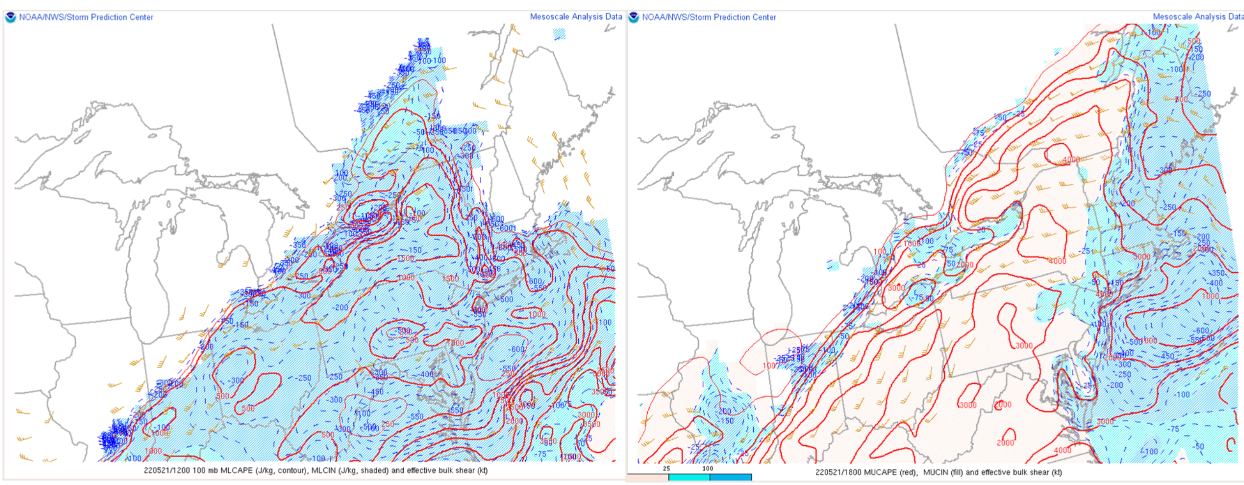

Figure 5: RAP analysis at 12Z on 21 May 2022 of mixed-layer CAPE and CIN (Convective inhibition), and effective bulk shear. The dark blue shading indicates the strong CIN across the region, with light blue indicated less CIN. On the right is RAP analysis at 18Z on 21 May 2022, showing the removal of convective inhibition as the day progressed.

Near Storm Environment:

Strong convective inhibition was present initially (Figure 5), but began to quickly erode, indicating that the forecast for the capping inversion to erode was going to become a reality. In the sounding shown in Figure 4, the forecast 700mb temperature was 9.8 °C and then by 20Z, it was forecast to be 6.8 °C (Figure 6). Conditions at the surface featured summer-like heat with temperatures in the mid to upper 80s and dewpoints into the mid to upper 60s as well. A stationary boundary was present across eastern Vermont and into New Hampshire as southeasterly winds advected maritime air into the region. This helped stabilize much of Vermont initially (Figure 7). A strand of cirrus clouds from thunderstorms that occurred the previous day was shifting across the region early afternoon, and temporarily limited instability over the Champlain Valley. Occasionally, a lake breeze from Lake Champlain will result in easterly winds in far northeastern New York, and converging with southwesterly flow, usually produces a few thunderstorms during the summer. This strand of cirrus clouds may have prevented the initiation of thunderstorms in the eastern Adirondacks, which allowed for the trigger for convection to come from the outflow boundary interaction of a strong mesoscale convective vortex in Ottawa and the lake breeze from Lake Ontario. New thunderstorms began to develop in Jefferson and Lewis Counties in New York, with new thunderstorms developing along the northern edge of cumulus up through the Adirondacks (Figure 8). These thunderstorms began to develop in an environment with most unstable CAPE values exceeding 3000 J/kg, locally up to 4000 J/kg. A result of the core of the elevated mixed layer being positioned overhead at 18Z Saturday May 21st, as noted through most unstable lifted index values approaching -9 (Not Shown). Thunderstorms would approach the Champlain Valley around 20Z-22Z (4 to 6 PM), and based on forecast soundings, there would be no convective inhibition as this activity moved eastwards.

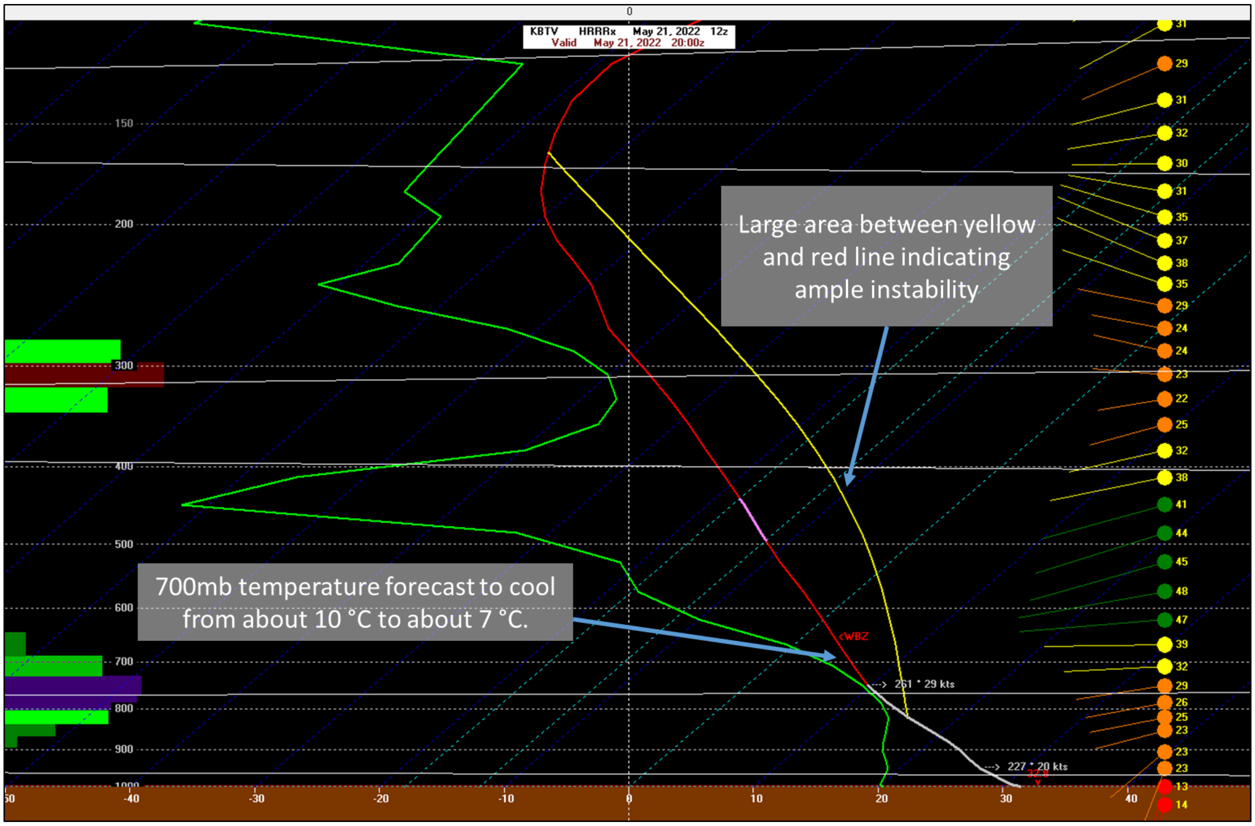

Figure 6: The forecast sounding from the 12Z HRRR for BTV at 20Z plotted using BUFKIT. The capping inversion was forecast to completely erode, producing this highly unstable sounding. The combination of dry air noted separation between the green and red line aloft and 40 to 45 knot flow in the mid-levels indicated the potential for dry entrainment and the mixing of strong winds towards the surface.

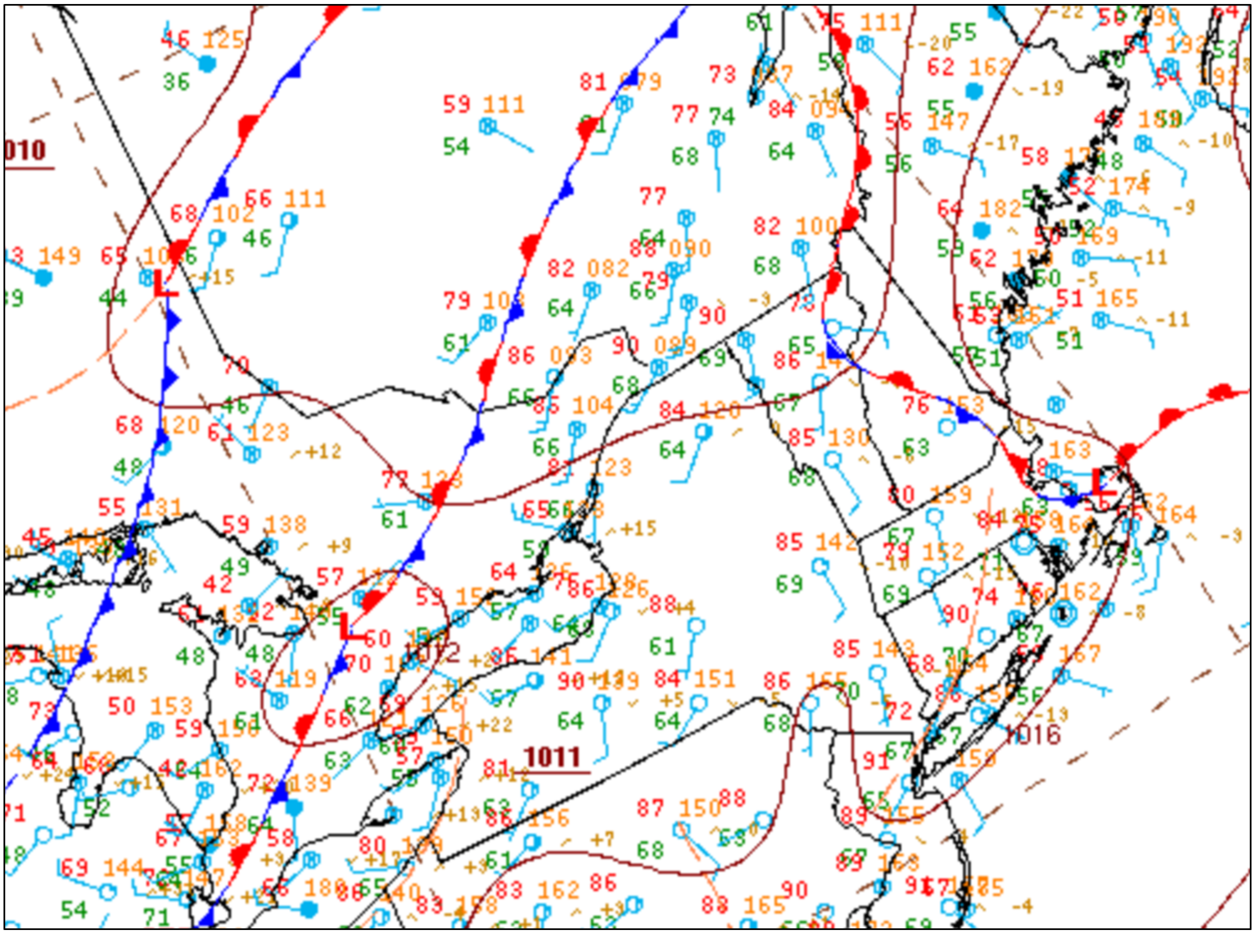

Figure 7: Surface Analysis from the Weather Prediction Center at 18Z on 21 May 2022. A stationary boundary was noted across far eastern Vermont into New Hampshire, where maritime air remained in place. Warm, moist surface conditions were present across much of Vermont and northern New York with temperatures in the 80s to near 90, and dewpoints in the mid to upper 60s.

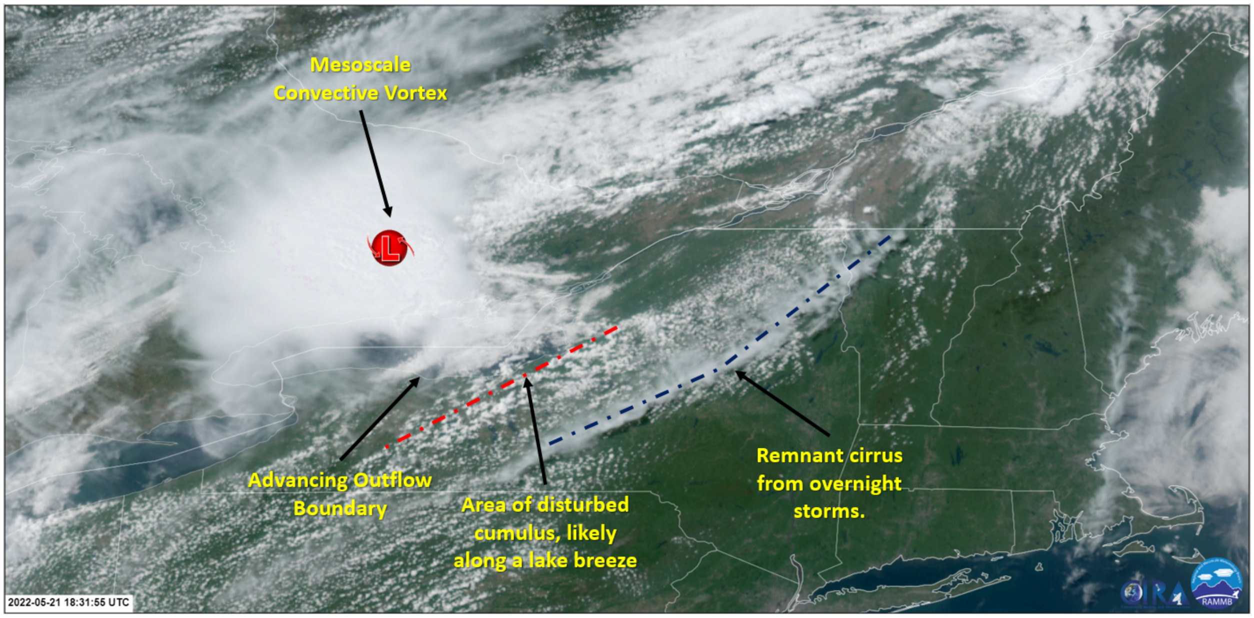

Figure 8: Geo-colored visible satellite imagery near 1830Z on 21 May 2022 provided through RAMMB. Relevant boundaries and features have been annotated. The mesoscale convective vortex that moved northeastward towards Ottawa produced an outflow boundary that helped initiate the thunderstorms we experienced.

Storm Analysis:

In total, six verified severe thunderstorms occurred on May 21st. Yet two were more significant. The first being a storm that developed near Willsboro, NY and traveled east towards Shelburne and Williston in Vermont, before traveling towards Stowe and Hardwick (Figure 9). The storm produced a number of downbursts that caused widespread tree damage, particularly in Williston, Vermont. The initial downburst took place on the western edge of Lake Champlain, seen through the pure divergent signature observed around 2131Z (5:31 PM). Scattered wind damage occurred along the eastern shores of Lake Champlain and Route 7, as well as a reported boat shoved onto the lake occurred from this first downburst. The second downburst occurred about ten minutes later (Figure 10). The divergent signature, adding the velocities towards and away from the radar, was approximately 65 knots at 2148Z (5:48 PM). More tree damage was reported with several uprooted, particularly near the Williston Country Club, in addition to downed power lines. The extent of damage closed Route 2 until the following afternoon. While less significant, the storm continued to produce strong, gusty winds that downed a few trees across Hardwick, Vermont.

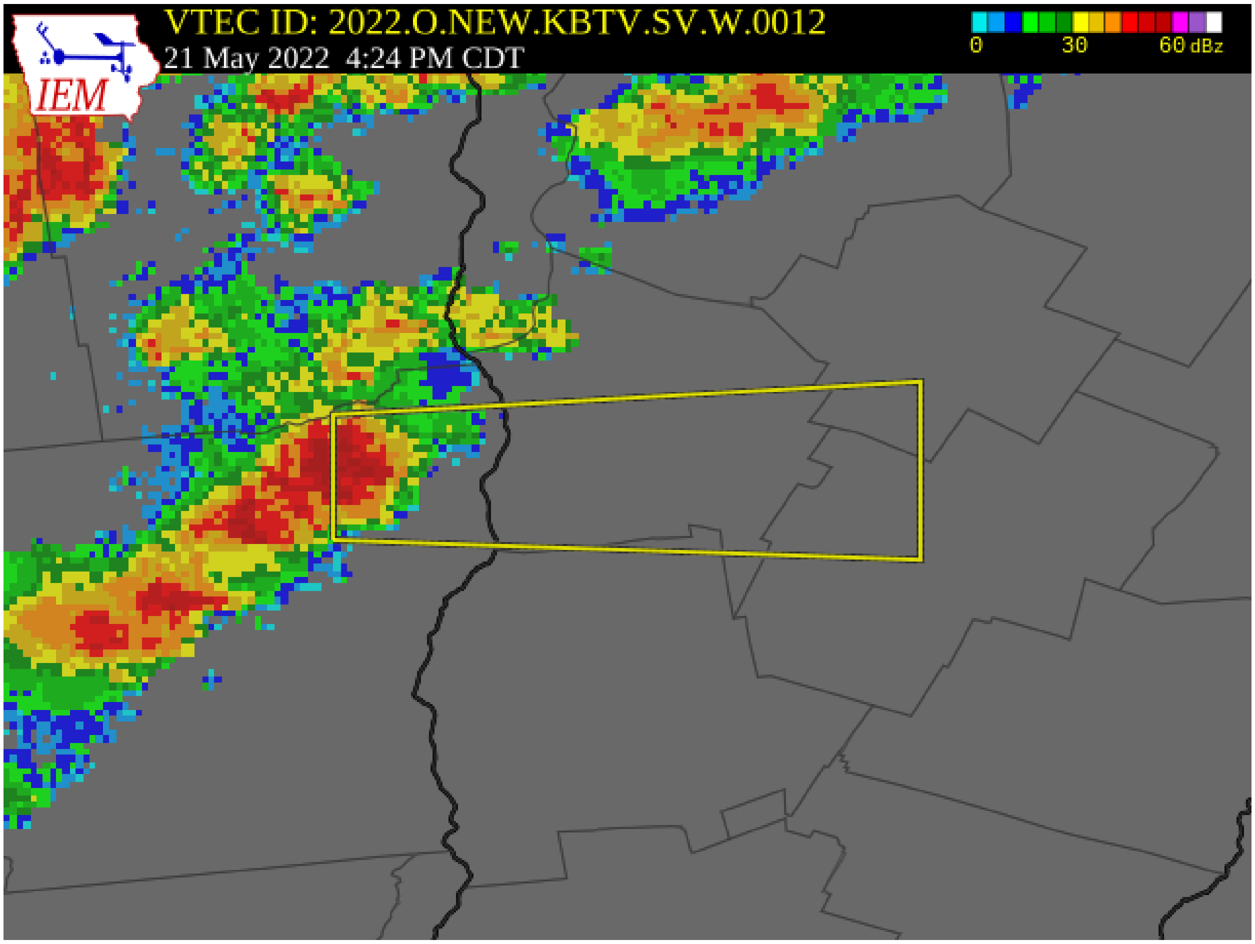

Figure 9: Severe Thunderstorm Warning 12, issued at 2124Z on 21 May 2022. This would be the thunderstorm that would track east towards Williston, and cause widespread tree damage. Image provided through Iowa Environmental Mesonet.

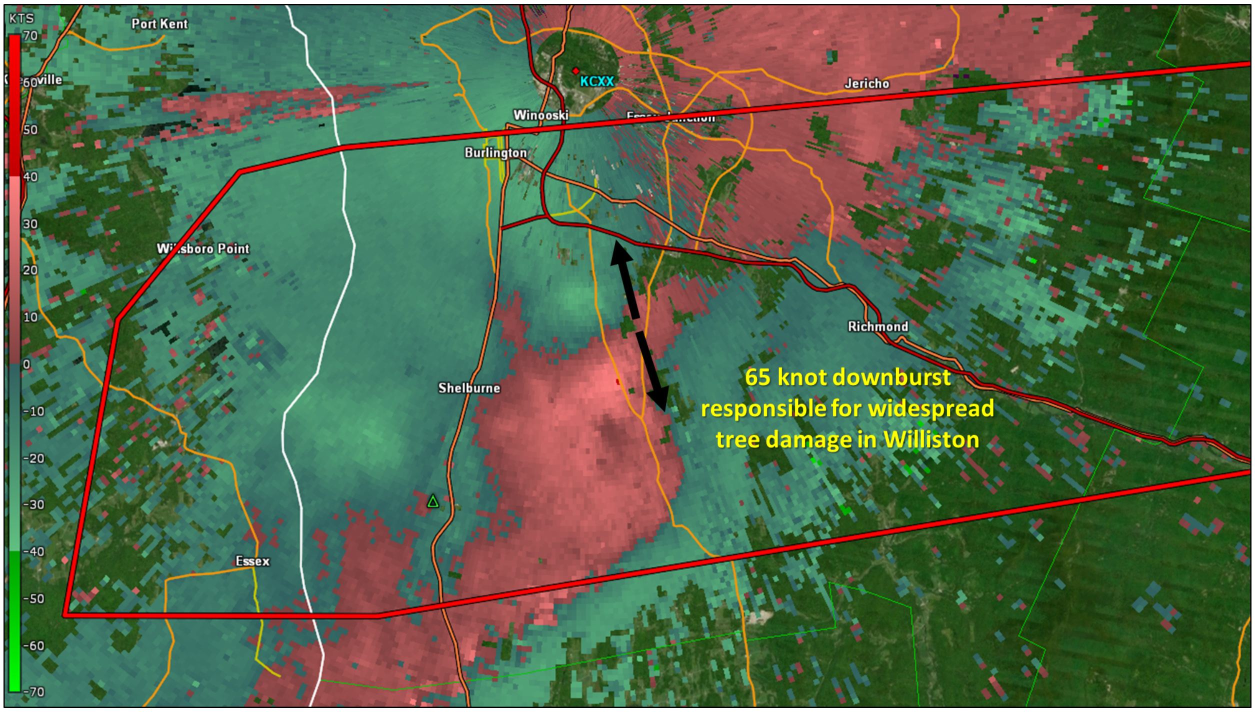

Figure 10: The second downdraft noted within Severe Thunderstorm Warning 12 at 2148Z on 21 May 2022. The divergent wind pattern observed from KCXX radar is shown using arrows.

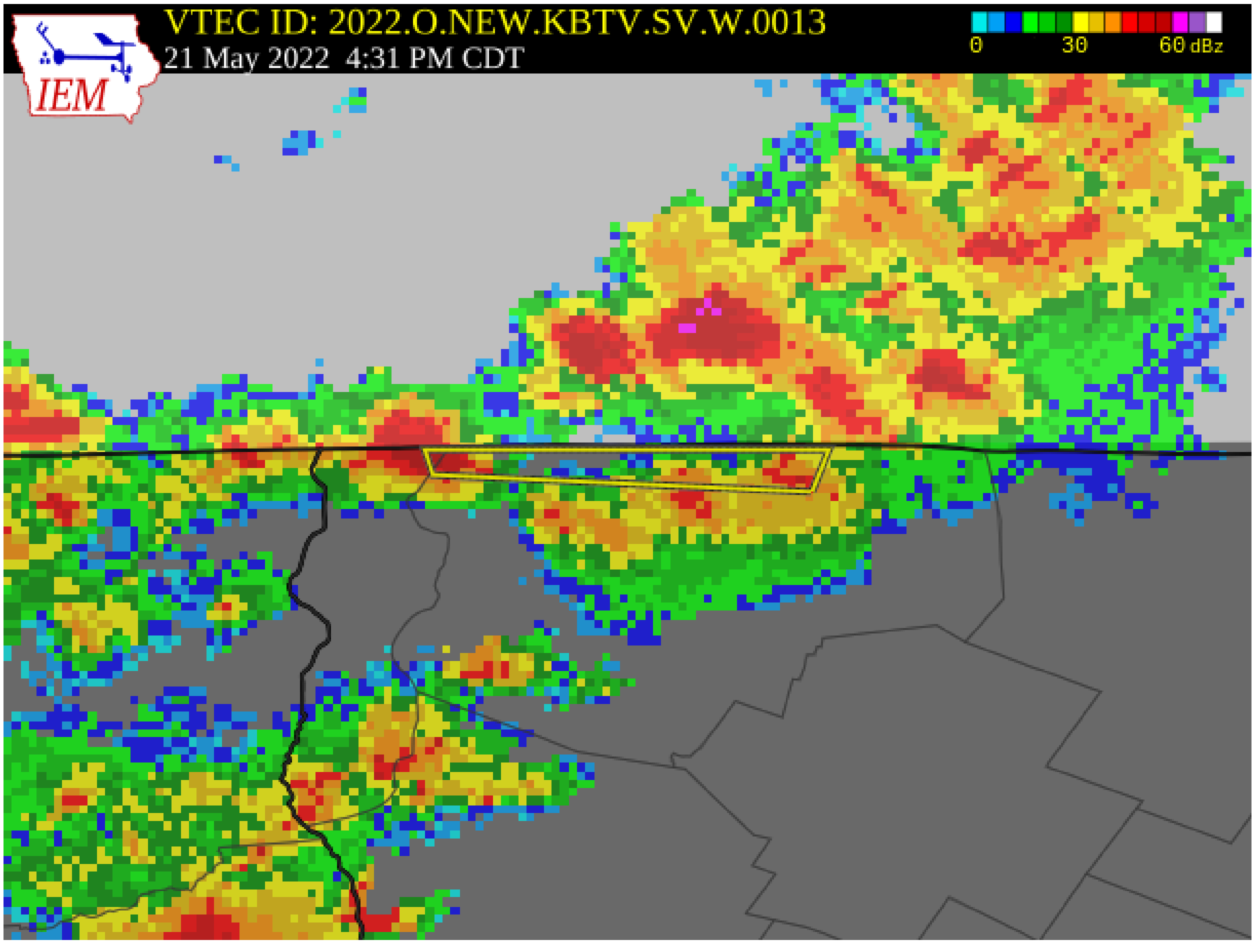

Figure 11: Severe Thunderstorm Warning 13, issued at 2131Z on 21 May 2022. This would be the thunderstorm that produced large hail across Highgate Springs. Image provided through Iowa Environmental Mesonet.

The second thunderstorm of note produced primarily large hail, but also some damaging wind (Figure 11). Developing along the international border with Canada, the thunderstorm began producing hail in Alburgh around 2130Z (5:30 PM). The storm intensified further, as the depth of the layer of probable hail increased and reflectivities increased to near 70 dBZ as high as 22000 ft above the radar elevation. Since hail scatters the radar beam differently than rain, it can be discerned often by reflectivities exceeding 60 dBZ. Not only were reflectivities greater than 60 dBZ present on one radial, it was present across multiple radials. The maximum estimated hail size (MESH), approached 3 inches (Not Shown). Although this algorithm is known to have a high bias in estimating hail size, this is a significant hail signal that is uncommon in the North Country. Also noteworthy was the depth of the hail core. Assuming reflectivities above 60 dBZ represents hail, the radar estimated depth of hail within this thunderstorm was nearly 30000 ft (Figure 12). Several reports and videos of hail across Alburgh, the northern edge of Swanton, and Highgate Springs were sent, and estimated hail size near 1.25” was reported. Before moving north of the international border, some tree damage was reported in northern Franklin, Vermont.

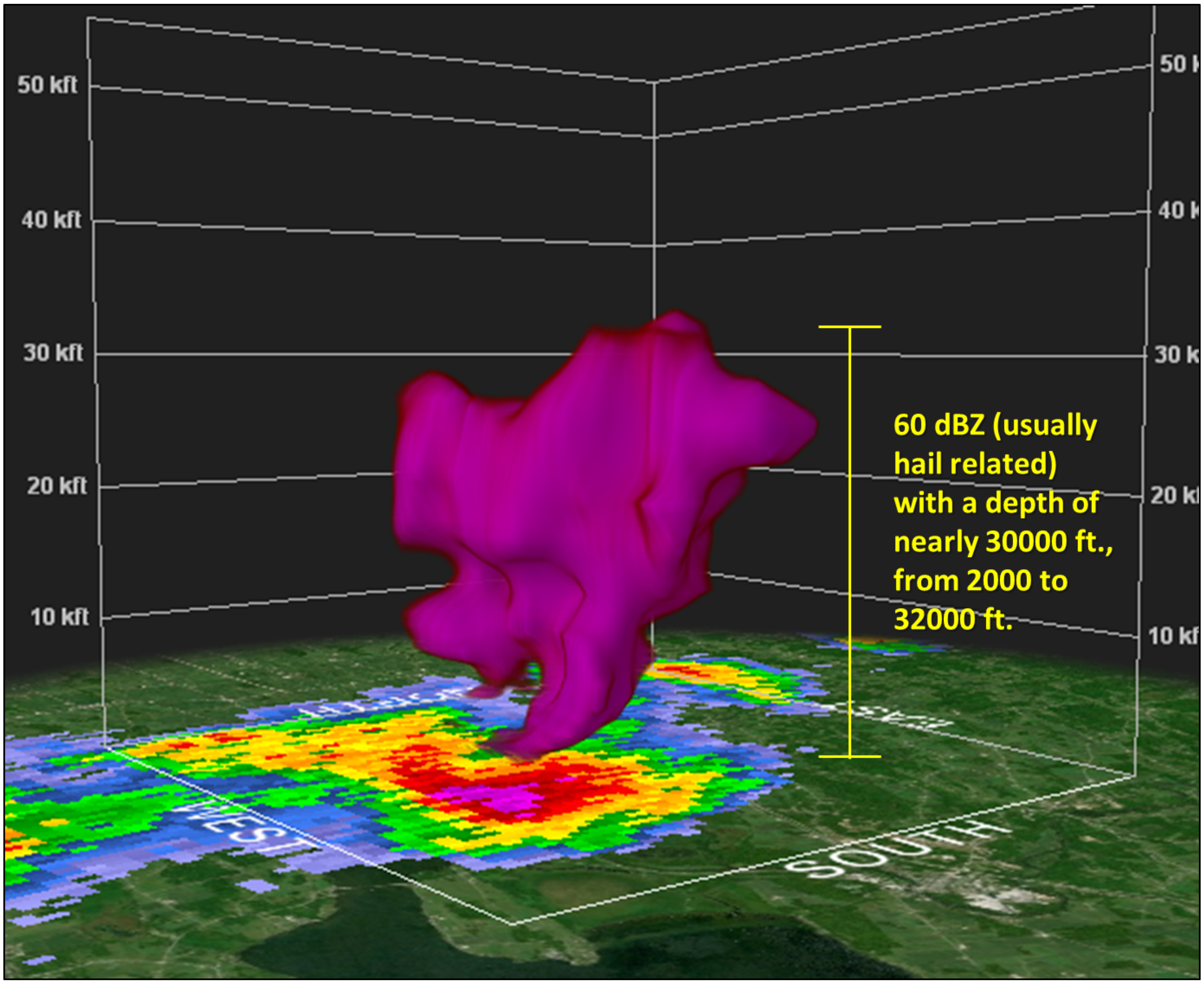

Figure 12: A three-dimensional view of the hail within Severe Thunderstorm Warning 13 at 2131Z. The purple colors indicate reflectivities greater than 60 dBZ. The vertical extent of the hail core was approximately 30000 ft.

Post-Storm:

On May 21st, scattered thunderstorms developed despite the lack of large-scale atmospheric forcing, as a result of mesoscale processes and mid-level cooling of a record-breaking warm layer. Beyond the initial trigger for thunderstorms, there was little to allow for upscale development of convection into a line or mesoscale vortex in our region. Convection was pulse-like, developing downshear (to the east) of ongoing convection. Thus, intense updrafts allowed for thunderstorms to rapidly develop and produce large hail and damaging winds. After precipitating out, all that would remain were remnant anvil clouds of each thunderstorm. As thunderstorms moved into eastern Vermont beyond 22Z, the loss of peak daytime heating and a more stable air mass resulted in overall lower intensity as thunderstorms shifted east into New Hampshire, though still capable of sporadic tree damage and sub-severe hail (Figure 13). Southern Vermont largely avoided any thunderstorm activity, where stable conditions prevailed for the entire day.

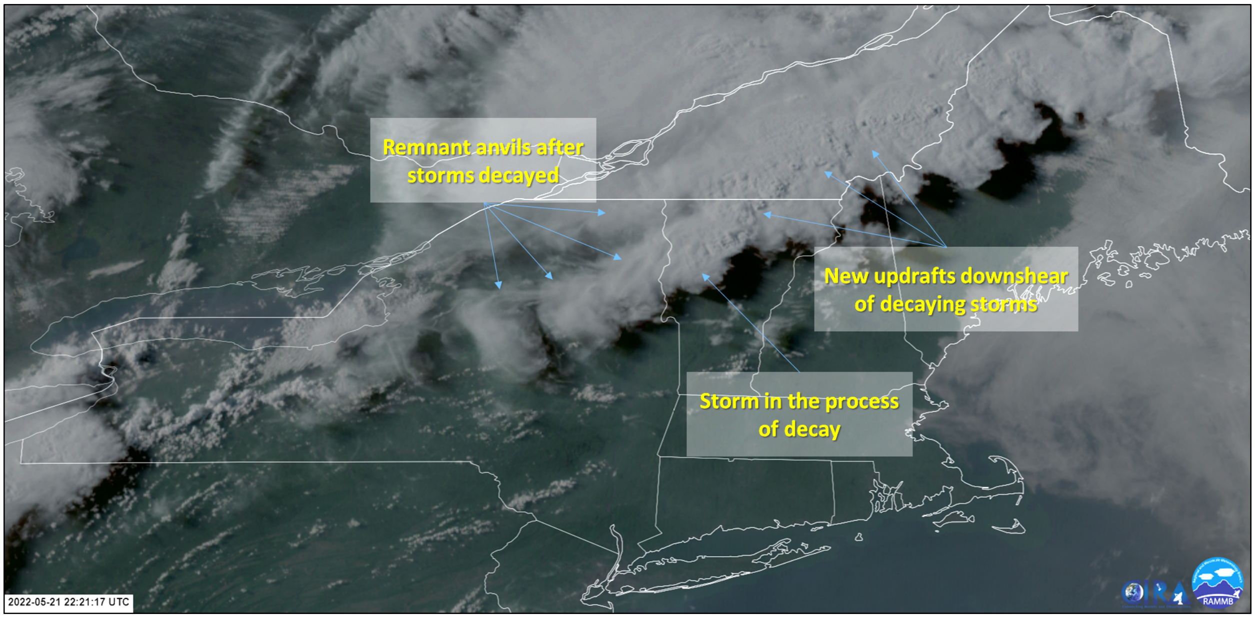

Figure 13: Same as Figure 8, but at 2221Z on 21 May 2022. Areas of decaying thunderstorms and where new thunderstorm development was occurring has been notated. New updrafts can be seen through overshooting tops above the canopy of clouds.

Photos:

Figure 14: Jon O’Connor took a photo and shared this excellent view of the shelf-cloud ahead of the storm in Williston, Vermont. Shelf clouds are a good indicator a storm is capable of producing strong winds and heavy rain.

Figure 15: NWS Burlington Warning Coordination Meteorologist snapped a photo of uprooted trees in Williston. Snapped trees, trees toppled onto power lines and structures were common in the area.

Figure 16: Two photos of hail in Highgate Springs (Left photo from Dawn Marie and right photo from Denise Tougas).